

1955

NEW ZEALAND
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

BULLETIN 115

Trace-element Deficiencies of Fruit Crops in New Zealand

By E. G. BOLLARD

Fruit Research Station, Auckland

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Trace-element Deficiencies of Fruit Crops in New Zealand

Introduction

THE first record of the effect of trace elements on fruit trees in New Zealand came from Nelson in 1935 when it was discovered that the disorder of apples, previously known as "drought spot" or "corky pit", was caused by boron deficiency. Since then it has been realized that trace-element deficiencies affect orchards in all the fruitgrowing areas of New Zealand. As a result of experiments undertaken in this and other countries, there is available today a large amount of information concerning the disorders of fruit crops due to trace-element deficiency. In this bulletin the published information on trace-element deficiencies of fruit trees in New Zealand has been assembled, and some hitherto unpublished results of work carried out at the Fruit Research Station have been included.

A general account is given of the occurrence of trace-element deficiencies, followed by a description of their detection and methods of treatment. Three separate sections on boron, manganese, and zinc follow, in which the specific disorders caused by deficiency of these elements are discussed and illustrated in more detail.

In addition to the references which follow the general section, a list of all original publications relating to the particular deficiency as it affects fruit crops in New Zealand is appended to each of the sections on boron, manganese, and zinc.

Publication of this bulletin is not meant to imply that our records are complete or that there is little left to discover on the subject. On the contrary, gaps in our knowledge are numerous. For instance, information concerning the importance of trace-element deficiencies in citrus fruits is not as complete as our information concerning pip and stone fruits. By summarizing existing knowledge, it is hoped that avenues for further work will be indicated.

Acknowledgments are due to officers of the Horticulture Division, Department of Agriculture, who, through their observations in the field, have been the first to call attention to several of the disorders discussed in this bulletin.

Occurrence of Trace-element Deficiencies

Elements Essential for Plant Growth

When a plant is chemically analysed it is found to contain most of the chemical elements found in soil. However, it soon became apparent to early workers on plant nutrition that not all of these are essential for the plant to make completely normal growth. Such elements as aluminium, lead, silver, and gold are found in plant tissues, but they appear to be there simply because they occur in the soil and are taken up by the plant along with the essential nutrients. Unless they reach high concentrations, their presence in the plant is completely passive as they apparently play no part in plant metabolism.

About one hundred years ago research workers were of the opinion that only seven mineral elements were necessary for the growth of plants—nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron. They were able to demonstrate this by growing plants in sand or water culture and supplying a nutrient solution containing these seven elements only. Using such solutions they were able to produce plant growth at least as good as that obtained in soil.

It was not till about 1900 that it was realized that other elements, such as manganese and zinc, also played some role in plant growth. By working with specially purified salts and water, it was demonstrated that these two elements also were necessary for normal plant growth, but the quantities required were very much less than for the other seven elements. It seemed that the earlier workers had unknowingly included manganese and zinc in their nutrient solutions by using insufficiently pure water or imperfectly purified salts. About 1923 boron also was shown to be essential, and in 1931 copper was added to the list. More recently, in 1939, the need for molybdenum was demonstrated. Most of this work was done with plants growing in water or sand culture, but the appearance in the field of disorders that could be remedied by additions of these elements provided the final and conclusive evidence of the necessity of these elements for normal plant growth.

There is now general agreement that these five elements—boron, copper, manganese, molybdenum, and zinc—are all essential for plant growth. Because they are required in minute quantities only, they have become known as minor or trace elements in contrast to the seven major elements. Micronutrients is another, and perhaps preferable, name suggested for this group. The important thing, however, is that they are just as essential for normal plant growth as are the major elements—the only difference being in actual amounts required.

The following list gives the level of each of the essential mineral elements likely to be found in the dried-leaf material of a typical healthy plant, in parts per million:

	p.p.m.		p.p.m.
Nitrogen, 2 per cent	= 20,000	Iron	- 100
Potassium, 1.5 per cent	= 15,000	Boron	- 40
Calcium, 1.5 per cent	= 15,000	Manganese	- 40
Magnesium	- 3,000	Zinc	- 40
Phosphorus	- 2,500	Copper	- 25
Sulphur	- 2,000	Molybdenum	- 1

It will be seen that the levels of boron, manganese, and zinc are only 0.2 per cent and the level of molybdenum only 0.005 per cent of the nitrogen present. Naturally the amounts of all the nutrients vary considerably, but the figures given here can be taken as a rough guide to the proportion of each normally found in plant tissue. Iron is not usually regarded as a trace element although it is present at a considerably lower level than other major elements.

The fact that the number of elements known to be essential has been added to from time to time suggests the possibility that further additions may yet be made. In fact, from time to time various suggestions are made regarding the essentiality of other elements. Claims have been made, for instance, that nickel, gallium, and cobalt might all be required. However, recent critical sand-culture work (Wallace, 1953), using highly refined materials, has shown that these three elements are not required by the tomato plant. It is not yet possible to say whether such results obtained with one species of plant are applicable to other plants. Recently in America a response to strontium has been obtained with peaches growing in the field (Wolf and Cesare, 1952), but this is the only report of its kind. It is probable that, should further elements be shown to be essential, they will be required in even smaller amounts than are the five recognized trace elements. Arnon and Wessel (1953) have recently presented evidence to show that vanadium is essential for the growth of a green alga, and they express the opinion that it is likely to be necessary to all green plants. It is puzzling, however, to find that it is apparently required in greater amounts than is molybdenum.

Trace Elements Essential for Animal Growth

Among the trace elements occurring in plants, a distinction must be made between those that are essential to the growth of the plant and those that, though apparently having no effect on the plant, are of vital importance to the health of animals which feed on plant tissues. Of the trace elements essential to plants, copper, manganese, and zinc are also essential to animals. In addition, two other elements, cobalt and iodine, which are normally found in plants, are essential to the health of animals consuming those plants. Soils deficient in either of these elements will produce apparently healthy plants, but stock feeding on them will suffer from deficiency diseases.

Function of Trace Elements in the Plant

It is of interest to consider what is known of the role of each of the trace elements in plant metabolism. The small amounts in which these nutrients are required by plants led to the early suggestion that they

functioned by accelerating chemical changes rather than taking part in them, i.e., they functioned as catalysts. Most of the chemical reactions that occur in living tissues take place under the influence of biological catalysts or enzymes. There are many of these in all living tissues, and it is their presence and activity that confer on any tissue most of its characteristic properties. Many of these enzymes function independently, but in some cases they have to be associated with another substance to be able to exert their effect. In some instances this extra part of the enzyme, or prosthetic group as it is called, is a metal, and it is these that interest us now. Zinc, copper, and manganese have all been shown to activate enzymes concerned with various stages of respiration—the fundamental process of all living tissue. Zinc is known to be the prosthetic group of one enzyme, while copper and manganese are each known to be the prosthetic groups of several enzymes. In each case the action of the metal is highly specific—no other known substance will take its place. It would seem likely then that these three elements are essential to plants because they are integral parts of enzymes concerned with respiration.

Not so much is known of the role of molybdenum and boron in plant metabolism. Molybdenum is known to be essential to the conversion of nitrogen absorbed as nitrate into the numerous organic forms required by the plant. The role of boron is still largely obscure. No enzymes are known in which these two elements act as prosthetic groups, but it is still possible that this is how they function. Our knowledge of enzymes is far from complete, and further work may reveal new enzymes to which these two elements are essential.

Deficiencies in Plants

When plants are unable to obtain an adequate supply of any one of the essential elements, the shortage becomes manifest by an over-all restriction of growth or by the development of abnormal conditions in some particular organs of the plant. Such a plant is said to suffer from a deficiency disease and the abnormal conditions are regarded as symptoms of that disease. This applies to both major and trace elements, but it is only the latter that are considered in this bulletin. For instance, both magnesium and iron deficiencies are important in fruit crops, but only passing reference will be made to these because neither of these elements is classed as a trace element.

Trace-element Deficiencies in Fruit Crops

In fruit crops throughout the world, specific disorders have been recognized as due to shortages of each of the five trace elements. Some of these are of local occurrence only, while others are widespread, affecting some fruit in most countries where that fruit is grown. In New Zealand, deficiencies of boron, manganese, and zinc affect many of the fruit crops to varying degrees. These disorders will be dealt with in detail later. There is little evidence that shortages of either copper or molybdenum affect any fruit crops in New Zealand.

Copper deficiency is responsible for a die-back disease of fruit trees in many countries, particularly Australia and America. This disorder is widespread and is known as "exanthema". Copper deficiency notably

occurs on peat soils, and in New Zealand a deficiency of this element has been noted in onion crops in the Marshlands district of Canterbury (Adams, 1948, 1949). Recent (Anon., 1954) chemical analyses of apple leaves from some poor Nelson trees have shown a low copper content. As far as the fruitgrower in New Zealand is concerned, there is little likelihood of copper deficiency occurring in any blocks of trees where Bordeaux sprays are used. In fact the method of treating copper deficiency is simply to apply such sprays. In any blocks where copper sprays have not been used, a deficiency of copper must always be given consideration as the possible cause of any disorder that may show up in the future.

Recently in Florida (Stewart and Leonard, 1952), a deficiency of molybdenum has been shown to cause a leaf-spotting and defoliation disease of citrus fruits. Though this is the only record of molybdenum deficiency affecting fruit crops in the field, water-culture studies (Hoagland, 1941) have demonstrated that a deficiency of this element causes dwarfing and mottling of leaves in young plum trees. In New Zealand there is a widespread shortage of this element, some crops, particularly clovers and cauliflowers, giving a marked response to applications of it. While there is no record of a deficiency of this element affecting any fruit crops here, this is a possibility that must continuously be borne in mind.

Distribution of Deficiencies in New Zealand

Table 1 shows the districts where boron, manganese, and zinc deficiencies have been recorded in fruit crops in New Zealand. It must be remembered that additions to this list may well be made in the future.

TABLE 1. DISTRIBUTION OF TRACE-ELEMENT DEFICIENCIES IN FRUITGROWING DISTRICTS OF NEW ZEALAND

	Boron	Manganese	Zinc
Kerikeri -	-	+	+
Auckland -	-	+	?
Hawke's Bay	-	+	-
Nelson -	-	+	?
Canterbury	-	?	-
Central Otago	-	+	-

+ = Positive identification.

? = Questionable identification.

- = No record.

The following points concerning this distribution are worthy of note:

- (a) Boron deficiency occurs to only a slight extent in Auckland and not at all in Hawke's Bay or Canterbury, but, in Nelson particularly and in Central Otago, it has been a serious problem.
- (b) Manganese deficiency occurs in all districts.
- (c) While zinc deficiency has been reported in Auckland and Nelson, it is certainly not serious in those districts. It has not been observed in Hawke's Bay or Canterbury. In Central Otago, however, particularly in the Alexandra district, it is the cause of a relatively serious disorder. Recently it has been shown that zinc is deficient in some citrus trees in Kerikeri.*

*Work done in collaboration with W. A. Fletcher, Citriculturist, and J. A. Cederman, Horticulture Instructor, Department of Agriculture.

- (d) Considering districts, Auckland and Hawke's Bay are worst affected by manganese deficiency, and Nelson by boron deficiency, while Central Otago suffers from all three deficiencies.

Fruits Affected in New Zealand

Not all types of fruit are affected by each deficiency. Table 2 lists the kinds of fruits affected by boron, manganese, and zinc deficiencies in New Zealand.

TABLE 2. TRACE-ELEMENT DEFICIENCIES OF FRUIT CROPS RECORDED IN NEW ZEALAND

		<i>Boron</i>	<i>Manganese</i>	<i>Zinc</i>
Apple	-	+	+	?
Pear	-	+	-	+
Quince	-	-	+	-
Plum	-	+	+	+
Peach	-	-	+	+
Apricot	-	+	+	+
Cherry	-	+	+	-
Raspberry	-	+	+	
Citrus	-	-	+	-
Passionfruit	-	-	+	

+ = Positive identification.
 ? = Questionable identification.
 - = No record.

The following points from this table are noteworthy:

- Boron deficiency has been recorded in all crops listed except quince, peach, citrus, and passionfruit.
- Manganese deficiency is known to occur in all crops listed except pear.
- Zinc deficiency is known to occur in citrus, pip, and stone fruit.

Where a fruit crop is shown as not subject to a particular deficiency, the reason may be that the particular crop has "escaped", e.g., citrus may never have been grown in a boron-deficient area or raspberries in a zinc-deficient soil. On the other hand some of the negative records are probably due to a difference in requirements for a particular element, e.g., peaches have been grown in areas subject to boron deficiency but have not been known to show deficiency symptoms.

Inter-crop and Varietal Differences

Crops are known to have different needs for trace elements or, at least, show different susceptibilities to trace-element deficiencies. Garner and Roach (1945) quote an extreme case where, of a range of plants growing in the one soil, some were affected by iron deficiency and others by manganese deficiency. More commonly one type of plant may be affected by a deficiency while others remain seemingly unaffected. It has already been mentioned that clovers and cauliflowers often respond to molybdenum in New Zealand, but no response to additions of this element has ever been made by any fruit crop here. In addition to fruit crops, the effects of boron and manganese deficiencies are seen in other crops, e.g., swedes (boron) and oats (manganese), but no evidence has

yet been presented of a deficiency of either of these elements in grasses or clovers. The range of plants known to be affected by zinc deficiency is very restricted.

Different reactions to trace-element deficiency may even occur between varieties of one type of fruit. For example, boron-deficiency symptoms are rarely seen in Delicious apples but are common in Sturmers. Newcastle apricots would seem to be more susceptible to zinc deficiency than other apricot varieties, and Paragon peaches appear to be particularly susceptible to manganese deficiency.

Trees of the one variety growing on different rootstocks may show different susceptibilities to trace-element deficiency. Bould *et al.* (1950) have described an instance of copper deficiency of apples where trees on Malling XII stock appeared to be more susceptible than trees on Malling I or Malling II. Zinc deficiency, on the other hand, was not associated with any particular rootstock.

It is not possible to say whether these differences between crops and between varieties are to be explained on a basis of either a differential requirement for trace elements or a differential ability to obtain these nutrients from soil.

Multiple Deficiencies

Instances have been reported where more than one element has been deficient in fruit trees at the one time. Thompson and Roberts (1945) have reported a case where cherry trees were simultaneously deficient in iron, manganese, and zinc. Fortunately such cases appear to be rare and none has been detected in fruit trees in New Zealand, though Askew (1944) has recorded a combined deficiency of boron and potassium in grapes in the Nelson district.

Symptoms of Trace-element Deficiency

It has already been mentioned that a deficiency of any one element becomes manifest by the development of characteristic abnormal conditions in particular organs of affected plants. Symptoms will be described later in detail for the range of fruit crops affected by each deficiency.

In many cases distribution of symptoms within any one tree is uneven. For instance, only a proportion of the fruit on a tree may show the pitting of boron deficiency, or only the leaves on one side of a tree may show chlorosis caused by manganese deficiency. With zinc deficiency, trees have been observed where one leader and its subsidiary growths appeared completely healthy, another leader showed chlorosis and "little leaf" symptoms, while a third leader showed die-back.

Irregular Distribution of Trace-element Deficiencies

Within a block, distribution of trees showing symptoms is often irregular. This is sometimes puzzling when a disorder is seen in the field for the first time. The orchard may have received uniform treatment and yet the disorder appears apparently scattered randomly through a block—

suggesting perhaps a pathogenic disorder rather than a nutrient deficiency. Yet many deficiency disorders show up in just this manner. Other things being equal, such differences must be due to non-detectable soil irregularities.

In many such cases there is probably only a slight difference in nutrient content between apparently healthy trees and ones showing quite severe deficiency symptoms, i.e., the apparently healthy trees may be on the threshold of showing such symptoms. Apparently normal trees may be restricted in growth or cropping capacity to an extent that cannot be detected.

Seasonal Variation in Occurrence of Trace-element Deficiencies

In many orchards the same trees have been known to show the same deficiency symptoms over several successive seasons. Nonetheless the extent to which these symptoms are shown does vary from season to season. Some of the factors influencing this variation affect the availability of trace elements in the soil, and these will be discussed in detail in the next section. If trees receive a heavy fertilizing with one of the major elements, the intensity of trace-element deficiency symptoms is reputed to increase. Again symptoms shown may vary with size of crop carried by the tree—generally the heavier the crop the more severe are the symptoms. In Central Otago, in a year when there was severe loss of fruit due to spring frost damage, deficiency symptoms were less severe than normal. Sometimes one branch of a tree will bear a much heavier crop than others, and such branches frequently show deficiency symptoms more severely than do lightly laden branches.

Availability of Trace Elements in Soil

Plants growing in a particular soil may be deficient in a trace element because the soil itself has a low content of that element. This may occur because the soil was derived from rocks originally poor in that element or because extensive leaching has taken place since soil formation. More often plants may be deficient even though the soil contains a sufficiency of the element concerned because it is present in a chemical form which the plant is unable to utilize. It is possible, too, that external factors may convert available forms to non-available forms. Changes in soil pH and soil water content are the most important of these factors. In such cases changes back to the normal state will again render that element available. From the field observer's point of view, however, the result is the same in all cases—plants suffer from a deficiency that can be remedied by supplying the particular element that is deficient.

Perhaps the most important factor affecting availability of trace elements is soil pH. The effect of increasing pH (i.e., making the soil more alkaline) is to increase the availability of molybdenum but to decrease that of boron, manganese, and zinc, while the effect on copper availability is not clear. For example, certain soils in the Hastings fruit-growing area have a pH of over 6.5, and in these areas manganese deficiency is commonly seen. The relatively high incidence of boron, manganese, and zinc deficiencies in Central Otago can probably be attributed to the high soil pH in most parts of that district. One of the

effects of adding lime is to raise the pH of a soil. For this reason fruit-growers, particularly in those areas where the pH of the soil is naturally high, should consider the effect on trace elements before liming their orchards. Deficiency symptoms can appear in trees after liming where no such symptoms have appeared before.

The effect of soil pH is strikingly illustrated in some citrus blocks in the Auckland district where only a few trees in one part of a block may show marked chlorotic symptoms due to manganese deficiency—the remainder of the block being quite free from such symptoms. Investigation has revealed that in the soil beneath affected trees are old Maori middens—large accumulations of discarded shells, which supply abundant lime in the vicinity of tree roots.

In a dry season, boron deficiency is always more severe. Apparently a reduction in soil moisture reduces the availability of boron compounds in soil. This phenomenon is well illustrated in the case of boron deficiency in apples. In a hot, dry season this disorder is always more severe—so much so that in the Nelson district it was known as “drought spot” (Rigg and Tiller, 1927) before its cause was understood.

There is some evidence that soil micro-organisms also play a part in rendering soil nutrients, particularly manganese and zinc, non-available to higher plants. Little is known, however, of factors influencing this or how extensively it occurs.

It is possible that different systems of orchard management may have different effects on availability of trace elements in the soil. It has been shown, for example, that trees under mown grass have a higher phosphate and potash status than adjacent trees under clean cultivation. Little is yet known about the trace-element status of trees under other forms of management, but it is possible that they vary similarly.

It is sometimes asked whether our orchards, as they become older, will become depleted in more of these essential elements. In some cases the probable answer to this question is “yes”, but it is impossible to generalize. Where soil contains a sufficiency of an element but most of it in a non-available form, it is probable that a proportion of this total will be constantly becoming available, replacing that which has been absorbed by plants. Under such circumstances it is unlikely that soils will suddenly become depleted of an element.

Detection of Trace-element Deficiencies

When trees in the field are showing symptoms that might be caused by trace-element deficiency, several methods are available for diagnosis of the particular cause of trouble. Some of these methods are indicative only, while others are more or less conclusive. From the following descriptions the scope and limitations of each method should be apparent.

Visual Symptoms

A deficiency of any one trace element produces reasonably constant symptoms and it is often possible to recognize the particular deficiency by these specific symptoms, but before this can be done the effects of

each deficiency must be well known. Much of the work towards this end has been done by Professor T. Wallace, of Long Ashton Research Station, and many of his findings are summarized in his book *The Diagnosis of Mineral Deficiencies in Plants*. This book also contains a series of coloured illustrations of symptoms produced by deficiencies of different elements, including trace elements, in a wide range of crops. An American publication which is not so copiously illustrated is entitled *Hunger Signs in Crops*. Both books are particularly useful when a new and unknown disorder is first encountered. The former is perhaps the more useful, but it does not cover citrus crops nor does it deal with zinc deficiency.

Though visual diagnosis can now be applied with a fair degree of confidence to many disorders affecting fruit in New Zealand, it must be emphasized that it is not possible to be completely certain of a diagnosis using this method. For example, boron deficiency symptoms are sometimes difficult to distinguish from other pitting disorders of apple fruits, and mild zinc deficiency symptoms are very similar to manganese deficiency symptoms in peaches and apricots.

In practice, even when a positive diagnosis is not possible, this method gives an indication of the elements most likely to be deficient, and these can be tested for by one of the other methods discussed in succeeding sections. Often with trace-element deficiencies the symptoms do not show up till late in the season—too late with deciduous trees for treatment to take effect that season. When this occurs, affected trees are marked and treated in the following season before symptoms appear.

Deficiency symptoms are easily confused with pathological symptoms caused by virus diseases, fungous diseases, etc. With some crops, particularly on acid soils, it is possible to confuse toxic symptoms, i.e., symptoms caused by an excess of an element, with deficiency symptoms, but this has not yet occurred with fruit crops. However, when a completely unknown disorder is encountered it is usually possible on the basis of visual symptoms alone to decide with some degree of probability whether or not the disorder is due to a deficiency.

In later sections of this bulletin symptoms of boron, manganese, and zinc deficiencies in fruit crops are described and illustrated in detail.

Soil Analysis

It would perhaps seem that a chemical analysis of soil should be a certain way of determining trace-element deficiency, but, in fact, soil analysis is of little help in diagnosis. The difficulty is that soils may contain an abundance of a given nutrient element in a form that plants are unable to use. There is as yet no precise definition of the chemical forms in which the various elements are available to plants. Until methods are developed for measuring this available fraction of each element, we can expect little help from soil analysis.

Biological assay methods have also been suggested for determining availability of trace elements in soils. Use has been made of a fungus, *Aspergillus niger*, which requires copper, manganese, molybdenum, and zinc for its normal growth. By measuring the growth rate of this fungus

on specially purified media to which the soils for testing have been added, it is possible to obtain a measure of the availability of these elements to this fungus. Unfortunately, results do not necessarily apply to other plants.

The fundamental difficulty in using any soil analytical data is the fact that plant varieties and species differ in their requirements for trace elements or in their ability to obtain these nutrients from soil. The result is that in a given soil one species may suffer from a deficiency while another will make normal growth. No chemical soil analysis can overcome this difficulty.

Where the soil scientist can perhaps give most help is in his classification of soil types on the basis of response obtainable to trace-element deficiencies. Soils may be classified into "suites", the members of which are derived from the same parent rock, but differ from each other in the extent to which they have been leached (Wright, 1953). It may be possible to give an over-all picture of the nutrients in any one suite, e.g., soils of a particular suite may all be boron deficient but within that suite the more leached types would be most deficient.

Plant Analysis

Chemical analysis of plant material has provided much information on the content of most elements concerned in plant nutrition, and, with the trace elements, valuable confirmations of diagnosis have been obtained. In this method the analysis measures nutrients that have been taken up by the plant from soil, and there are no questions of availability to obscure the issue. Leaves are usually regarded as the most suitable plant organs for analysis, though, with boron deficiency, fruit tissues have also been used.

Before full use can be made of this method it is necessary to establish nutrient levels that may be expected in normal and deficient tissues. This is not simply a matter of establishing one critical level for each element in each plant, for different levels are to be expected at different times of the year. Care has to be taken that leaf-sampling methods are standardized, as there are differences between leaves growing on different parts of the tree. It is usual to select leaves for analysis from the lower and middle portions of current season's growth. Different critical levels can be expected in different plant species, e.g., lemons have been known to show boron-deficiency symptoms with 30 p.p.m. of boron in their leaves. Many other plants at this level are well supplied. Stone fruits show symptoms of manganese deficiency when their leaves contain about 15 p.p.m. of manganese, but at this level citrus species show no symptoms. Differences may also be expected between varieties of the one fruit or between trees of the one variety growing on different rootstocks. The matter is further complicated as it seems that the absolute content of an element is not the only factor which determines whether the ill effects of a deficiency will show up. In some cases the ratio of this element to other elements is also important.

Our lack of precise information on these points reduces the value of this method. Establishment of critical levels for each of the elements in

varieties of fruit we are concerned with in this country must take some time. Some details are known for some kinds of fruit, but there is much work still to be done. Roughly, deficiency symptoms can be expected when the level of any of the three elements we are concerned with—boron, manganese, and zinc—falls below 20 p.p.m. in dried-leaf material.

Because these elements are present in plant tissue in such low concentrations, their quantitative analysis presents considerable technical difficulties. Compared with the determination of nitrogen, for example, the measurement of any one of the trace elements is more difficult, takes more time, and is more expensive. For these reasons, and because of the other difficulties discussed above, it is not possible to contemplate anything in the way of a routine analysis service for trace elements in fruit trees.

Indicator Plants

Certain plants are known to be particularly prone to certain deficiencies, and some of these, usually annuals, can be used as indicator plants. Thus swedes are a good indicator for boron deficiency, oats and beans for manganese deficiency, and cauliflower for molybdenum deficiency. No suitable indicator for zinc or copper deficiencies is known. If a tree is suffering from an unknown disorder and a deficiency of, say, boron is suspected, then, if swedes are growing close by under the same conditions, an inspection of the swedes for boron deficiency should show whether or not boron deficiency in the tree is likely. If the swedes are not showing symptoms, the probability of the tree suffering from boron deficiency is reduced.

Within an orchard a comparison between trees is sometimes helpful. Peaches are probably more prone to manganese deficiency than other fruits, and if pears, for example, are showing an unknown leaf chlorosis, then an examination of any nearby peaches should be carried out. If the peaches do not show symptoms of manganese deficiency, it is less likely that the pears will be suffering from this disorder.

It has been mentioned previously that considerable soil variations can occur over a comparatively small area; for this reason any indications of deficiency obtained by this method should be regarded as tentative only. Garner and Roach (1945) report instances of some plants suffering from manganese deficiency and others, growing in the same soil, from iron deficiency. In such cases the use of indicator plants could have led to wrong conclusions.

Addition of Suspected Missing Elements

One of the most useful methods of diagnosis is to apply the suspected missing element or elements to affected plants and watch for a response. There are various ways in which this application can be made.

Soil Treatment.—In general, trace elements are not added to soil because, in many cases, they are rendered non-available, and the tree will not benefit. In the case of boron deficiency, however, the addition of borax to the soil does allow trees to take up extra boron, and this procedure can be used both to detect and to treat boron deficiency.

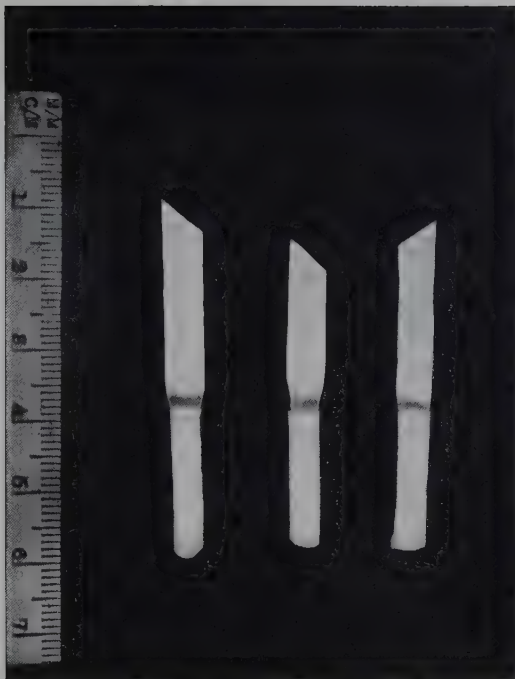


FIG. 1

Photo: J. W. Endt

Cups, made from drinking straws and filter paper, which are used for leaf-blade injection

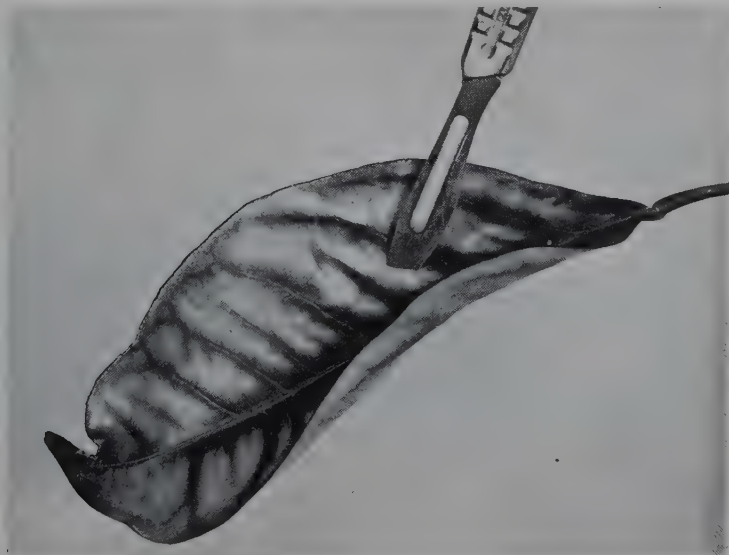


FIG. 2

Photo: J. W. Endt

A cut is made in the leaf blade with a sharp scalpel



FIG. 3

Photo: J. W. Endt

The filter paper wick of the cup is threaded through the leaf blade



FIG. 4

Photo: J. W. Endt

The cup is filled with a solution of the test element from a dropper



FIG. 5

Photo: J. W. Endt

The cup is pulled tight against the lower leaf-surface and most of the filter paper wick is cut off with scissors. The solution can then move through the wick into the leaf

Spray Application.—This is an extremely useful and widely used method consisting simply of spraying a suitable compound of the missing element on trees in leaf. Its efficacy depends on the ability of plants to absorb nutrients through leaves. Most fruit-tree species seem to be able, in this way, to absorb sufficient of the trace elements to rectify deficiencies. Care must be taken with the strength of spray used, and this will be discussed later under treatment of deficiencies. Often a response to spray treatment can be observed within a month of application. A response to manganese sprays has been seen in New Zealand grapefruit within fourteen days.

In some cases deficiency symptoms appear to be irreversible. This is true of fruit-pitting symptoms of boron deficiency, and it also seems to apply to the leaf-chlorosis symptoms of other deficiencies. Some of these symptoms do not appear till late in the season, and sprays applied in, say, January or February, while preventing the appearance of symptoms in any further growth, have no effect on the leaf chlorosis already present. A genuine response might well be masked by such an effect. In these cases it is necessary to mark affected trees and apply diagnostic sprays before symptoms appear in the following season. If this is done, no symptoms should appear in trees sprayed with the missing element, but they will develop in trees left unsprayed and in others sprayed with non-deficient elements.



FIG. 6

Photo: J. W. Endt

A hole is bored in a branch with a brace and bit



FIG. 7

Photo: J. W. Endt

A glass tube and stopper are inserted into the hole in the branch



FIG. 8

Photo: J. W. Endt

The final assembly showing the reservoir from which the test solution feeds by gravity into the branch

A modification of the foliar spraying method, which is used when only a small number of trees is affected, is the leaf-painting method. Here solutions of the suspected deficient elements are painted on to individual leaves or groups of leaves showing deficiency symptoms.

Plant Injection.—It is possible to inject solutions of deficient elements into plants. This may be done on a small scale by injection of solutions

into individual leaf blades, into leaf stalks, into shoot tips or, on a larger scale, into woody stems. It is even possible to inject the elements in solid form into woody stems. Many of these injection methods have been devised by Dr W. A. Roach, of East Malling Research Station (Roach, 1938; Roach and Roberts, 1945). Roach's leaf-blade injection method is illustrated in Figs. 1-5, while Figs. 6-8 illustrate a method of branch injection.

These methods require skill and practice, but are often used when other methods have failed to give a satisfactory answer. Injection methods are usually regarded as the ultimate in diagnostic methods—if there is no response to an element actually forced into the plant tissues, it is unlikely that a response will be obtained in any other way. At the same time the remarks made above concerning the irreversible development of symptoms can also apply to this method.

With any of these addition methods—spraying, injection, etc.—it is most important to use pure compounds of the elements concerned. Even traces of other elements are liable to lead to erroneous conclusions. The classical illustration of this was provided during early work on "little leaf" of fruit trees in the United States. An apparent response of affected trees was obtained after application of iron sulphate. Subsequent work, however, revealed that it was an impurity in the iron sulphate that was causing the response. Purified iron sulphate produced no response while small applications of the impurity—zinc sulphate—produced the same response as was obtained originally.

Provided that the purity of chemicals is assured, a response obtained from any of these addition methods is usually unequivocal.

Diagnosis in Practice

None of the foregoing methods is used to the exclusion of others, and in actual practice a combination of several methods is most commonly used. The visual symptoms of a new disorder usually suggest the first possibilities; indicator plant considerations may confirm or preclude some of these possibilities; plant analysis may suggest a deficiency of one particular element, and actual application of this element to affected trees in the following season may produce a growth response or prevent the production of symptoms of the disorder seen in the preceding season.

Treatment of Trace-element Deficiencies

Once diagnosis of a trace-element deficiency is obtained by any of the foregoing methods, its correction is usually a straightforward matter, merely involving application of a suitable compound of the element in question. Borax, manganese sulphate, and zinc sulphate are the three compounds most generally used to correct the three deficiencies with which we are concerned. These three materials are in ready supply and are relatively cheap. Recommendations for the control of each deficiency will be discussed in detail in later sections, but a general account of factors involved in the different treatment methods will be given here.

Most orchardists are anxious to correct boron and severe zinc deficiencies once these have been identified in their orchards. Some growers, however, are content to tolerate many trees on their property showing manganese or mild zinc deficiency symptoms, believing, presumably, that there is little effect on the tree. It is difficult to see or measure the ill-effects of such a deficiency, but it would be surprising if reduced vigour and cropping did not result. For this reason every effort should be made to correct even mild deficiencies, especially as this can be done easily and with little expense.

Where a deficiency of a trace element has been identified, it probably means that levels of this element are generally low through all the fruit crops in that orchard, and, although most trees may be free from apparent deficiency symptoms, many may be on the threshold of showing such symptoms. Even apparently normal trees may be restricted in growth or cropping capacity. In such cases the deficient trace element might well be applied with benefit to the entire block and not only to trees showing obvious symptoms. For instance, one grower reports that, since applying zinc to his entire orchard and rectifying some obviously deficient trees, other trees, which previously were apparently healthy, are now bearing considerably larger crops, owing to a large reduction in fruit drop.

Soil Application

For the reasons previously discussed, manganese and zinc are not usually supplied by soil dressings, while borax is frequently applied directly to soil. It may also be added in the form of "borated superphosphate", i.e., ordinary superphosphate with which 2.5 per cent of borax has been mixed.

Attempts have been made (Healy, 1953) to treat manganese deficiency of peaches in Hawke's Bay by placing manganese sulphate in a trench in intimate contact with the roots of a deficient tree. This produced an excellent response in the first season, but in succeeding seasons was much less effective. It appeared that comparatively large amounts of manganese sulphate were rendered unavailable in that time.

It is easy to cause death or damage to trees by excessive soil applications of these compounds. Young apple trees have been killed by the application of $\frac{1}{2}$ lb. borax, while mature trees have been damaged by applications of 6 to 8 lb. borax or 5 lb. manganese sulphate.

Spray Application

When recovery cannot be brought about by soil dressings, deficient elements must be supplied as foliar sprays. In orchards this is a method readily carried out with existing equipment. The principles involved are the same as those discussed under spray diagnostic methods.

For treatment of manganese and zinc deficiencies, solutions of manganese and zinc sulphates are used. Because solutions of these salts at the required strength can damage the foliage of many plants, it is often necessary to include hydrated lime in the spray mixture in exactly the same way that hydrated lime is added to copper sulphate solutions to

prepare Bordeaux spray for therapeutant use. An effective strength is 3 lb. of manganese (or zinc) sulphate plus 4 lb. of hydrated lime in 50 gal. water. Sprays of this strength have been applied without damage to most fruit crops grown here.

Boron can be supplied to trees as a borax spray—a strength of 1 to 2 lb. in 100 gal. water has been shown to be effective in treating boron deficiency in apples. This spray can be applied safely without lime.

There is no record of any damage resulting from over-application of any of these trace elements when applied as sprays.

Addition of lime to manganese and zinc sprays produces a visible deposit after spraying. It is sometimes argued that to produce such an insoluble residue is to defeat one's purpose of supplying the plant with the missing element, but it is essential with some crops to avoid leaf injury. However, there is no doubt that these sprays are efficacious in remedying deficiencies, and it is possible that they might be more effective than straight solutions of the salts. These spray residues adhere strongly to the leaf surface. Residues of a manganese spray have been seen on leaves of New Zealand grapefruit in the Oratia district, Auckland, more than a year after application. Such a residue may provide a source from which the required element is slowly available over an extended period.

The time of application of these trace-element sprays is important. With deciduous trees the best time is early spring. There must be a reasonable leaf cover, say three or four fully opened leaves on new shoots, to absorb the spray. Sprays are effective later than this, but there is a much better chance of complete recovery with early sprays. If sprays are not applied till leaf symptoms appear, it is possible that new growth subsequently produced will be normal, but symptoms may remain in older leaves. Every effort should be made to get these sprays applied by the end of November. With evergreen trees, such as citrus species, the time of application may be of importance too, although the trees carry leaves for the entire year. It is possible that older leaves may not absorb nutrients as effectively as young leaves. One suitable time would appear to be after trees have begun their spring flush of growth.

With manganese sprays, including hydrated lime, it is important for another reason to make early application. This spray leaves a black deposit on foliage, and, if not applied early enough, will leave a similar deposit on fruit. With a hairy-skinned fruit like peach, this deposit may still be visible at harvest time. However, with all except the earliest varieties, no difficulty should be experienced with sprays applied before the end of November.

It has been suggested that a suitable time for spraying trees with trace elements would be in the autumn after the fruit is picked but before leaf-fall commences. This has been tested for manganese deficiency in peaches.* The trees receiving autumn spray application showed just as severe symptoms of manganese deficiency in the following season as did

*Work done in collaboration with D. W. Wilson, Horticulture Instructor, Department of Agriculture.

untreated trees, while trees which received a spring spray at the same strength were free from symptoms.

It is possible to remedy zinc deficiency in deciduous trees by strong sprays of zinc sulphate applied while the trees are dormant. Strengths of 25 to 50 lb. per 100 gal. water are used and, at this period of the year, these can be safely applied without lime. In the United States this is the recommended method for the initial treatment of severe zinc deficiency. Apparently, enough zinc is absorbed through buds or bark to last the tree through the following growing season. The possibility of treating manganese and boron deficiencies in the same way has not been fully investigated.

There is not enough information available to determine the number of foliar sprays necessary to control trace-element deficiencies. In most cases encountered in this country, one spring application has proved sufficient, but whether one application is effective for more than one season is still an open question. Though it would seem at present that annual sprays are necessary, future work may show that after a succession of annual sprays there is sufficient build-up of deficient element in the tree to enable one or more sprayings to be omitted without the consequent reappearance of deficiency symptoms.

It would be of considerable help to the orchardist to be able to supply a deficient element by incorporating it in a routine therapeutant spray, and this is possible in many cases. Borax is compatible with lead arsenate, colloidal sulphur, and lime sulphur. It is probable that zinc and manganese sulphate sprays (including lime) will have the same compatibility relations as has Bordeaux mixture. The compatibility relations of these trace elements with the newer therapeutant materials are being worked out and, in future, these materials will be included in the spray compatibility charts issued by the Plant Diseases Division.

A very recent development in the treatment of trace-element deficiencies is the use of complex organic salts of the elements rather than sulphates. Such complex compounds of zinc and manganese have been made, but there is no analogous boron compound. Small quantities of both zinc and manganese compounds have been available for testing here, and it has been shown that the manganese compound, applied as a spray, will remedy manganese deficiency in peaches. The zinc compound has not received adequate testing. While there are undoubted advantages in the use of the iron complex salt over ordinary iron salts in the treatment of iron deficiency, there appears to be little likelihood that there will be any advantage in the manganese and zinc compounds applied as sprays over the more commonly used manganese and zinc sulphates. It is claimed, however, that these organic compounds are effective when applied to the soil but, with the manganese and zinc compounds, this has not yet been adequately tested.

Some of the newer fungicides contain zinc (e.g., Zineb, Ziram) or manganese (e.g., Manzate) in organic form and it is possible that such materials, applied as therapeutants, might be capable of supplying zinc

and manganese respectively to the plants which are sprayed, but there is no proof of this yet.

Tree Injection

When discussing diagnostic methods mention was made of various ways of injecting plants. It is possible to use the branch and trunk injection technique as a field treatment. There are considerable disadvantages, however. The method is laborious, holes in the trunk may weaken it structurally, and it is possible that infectious diseases, such as silver leaf, could gain admittance through the holes. Injection as an orchard practice is not recommended under New Zealand conditions.

Soil Amendment

It has been pointed out that many of the field occurrences of trace-element deficiency arise from lack of available nutrient rather than any absolute shortage of that nutrient in the soil. Where lack of availability is due to high soil pH, it should be possible to render the element available by acidification of the soil which can be done simply by adding acid to the soil or, more cheaply, by adding sulphur, the latter being converted into acid in the soil by bacterial action. In practice, however, the desired results are more difficult to achieve.

In the Alexandra district attempts were made to reduce a soil pH of 7.5 by the addition of sulphuric acid. Over a period of four years a total of 12 gal. concentrated acid was added to a plot measuring 60 ft. by 40 ft. (occupied by six trees). At the end of this period the soil pH was down to between 6.0 and 6.5.

In the Hastings district, attempts were made (Healy, 1953) to treat manganese deficiency of peaches occurring in a soil of about pH 7.5 by the addition of sulphur at rates of up to $1\frac{1}{2}$ tons per acre. Two to three years after treatment the pH was down to less than 6.5, but, after that time, the values began to rise again, suggesting that the ground water rose through lime layers during wet periods. This would probably mean that a permanent reduction in pH in that area is not practicable.

These two experiments have demonstrated that reduction of soil pH is not a practicable means of treating trace-element deficiencies in two important fruitgrowing areas of New Zealand.

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Boron Deficiency of Fruit Crops in New Zealand

Introduction

In 1923 it was demonstrated that boron was essential for growth of broad beans, and since then a wide range of plant species has been shown to be affected by a deficiency of this element. Disorders due to boron deficiency, many of them serious, occur throughout the world and affect a wide range of crops, including beet, swedes, cauliflower, celery, lucerne, hops, and tobacco, as well as many fruit crops. In most of these plants boron deficiency causes a breakdown of storage tissue, e.g., "brown heart" of swedes, "hollow stem" of cauliflower, "cracked stem" of celery, rather than producing leaf symptoms or growth inhibitions characteristic of deficiencies of other elements. The deficiency occurs on a range of soil types and is aggravated by both liming and dry conditions.

Incidence in New Zealand

In 1935 Atkinson showed that the long-known disorder of apple fruits in the Nelson district, variously known as "drought spot", "corky pit", or "internal cork", could be rectified by treatment with boron compounds. Askew and Williams (1939) described boron deficiency in apricots, and recently (Askew *et al.*, 1951) it has been reported in raspberries. In the Nelson district, particularly on the Moutere hill country, this deficiency was very serious in apples in the past, particularly in dry seasons. In

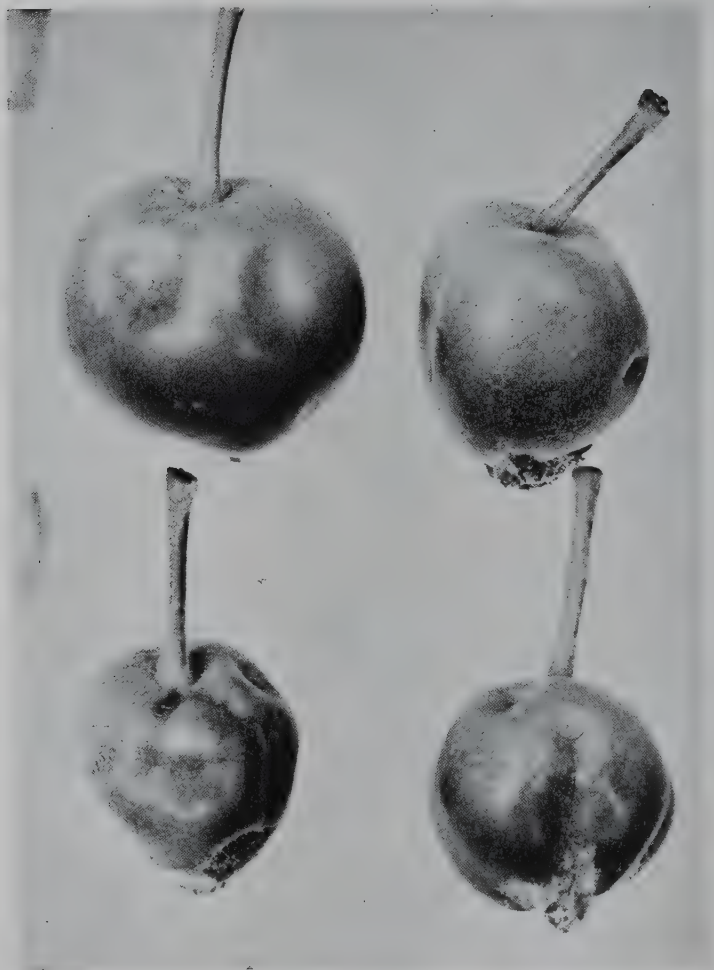


FIG. 9

Photo: S. A. Rumsey

Boron deficiency: Severe distortion of young Sturmer apples in early December. $\times \frac{5}{8}$

Central Otago the disorder has been serious in apples, and stone fruits have also been affected. Boron deficiency has been found only rarely in fruit crops in Auckland and not at all in Hawke's Bay.

Boron deficiency causes a serious disorder of swedes in many parts of the country. Tobacco, hops, celery, and cauliflower crops are also affected in deficient areas.

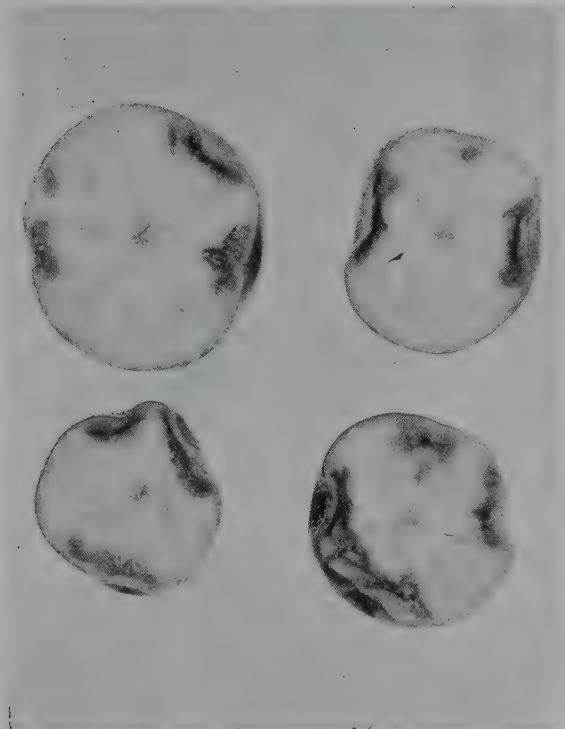


FIG. 10

Photo: S. A. Rumsey

Boron deficiency: Pitting of flesh of young fruit shown in Fig. 9. $\times \frac{5}{4}$

Symptoms

¹ In all tree fruits, symptoms are to be seen in the fruits themselves. The flesh develops brown pits which usually become corky in texture. Distortion of fruit may occur.

In apples, symptoms can appear quite early in the season—fruits already badly affected have been seen in early December (Figs. 9, 10). In mature apples the characteristic symptom is the presence of a number of brown, corky pits in the flesh (Figs. 12–14). These may be confined to the cortex but, in many varieties, pits appear throughout the flesh and within the core zone. In severe cases large cavities occur in the flesh (Fig. 14). Externally the apple may appear normal or there may be surface pitting. In some varieties there may be extensive malformation of the entire fruit (Fig. 11). Fruit of the varieties Delicious and Dougherty are rarely affected by this disorder. In Jonathans, damage is usually confined to pitting in the core region (Fig. 13). Cox, Gravenstein, and



FIG. 11

After Atkinson (1936)

Boron deficiency: External malformation of Sturmer apples

Ballarat rarely show external symptom, but pitting of the flesh is common. In Sturmer and Washington, severe malformation of the fruit frequently occurs in addition to extensive pitting of the flesh (Figs. 11, 12, 14). In the latter variety cavities are likely to appear in the flesh.

Pears affected by boron deficiency show a pitting of the flesh. In apricots (Fig. 16) there is malformation in addition to pitting of the fruit.

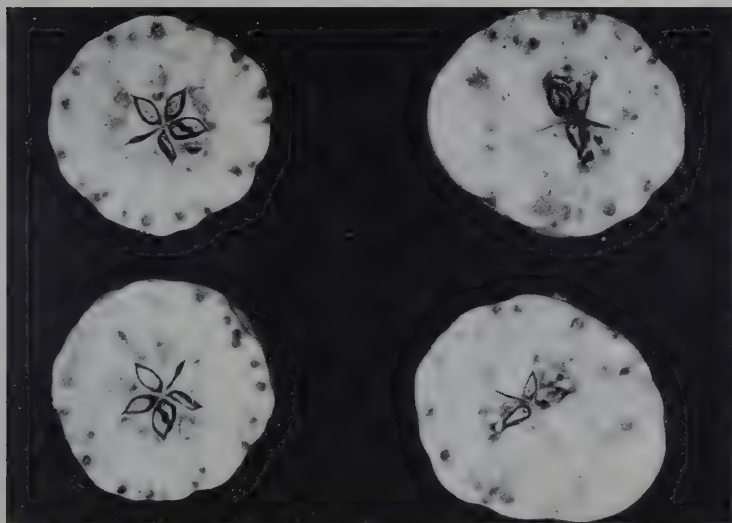


FIG. 12

After Atkinson (1936)

Boron deficiency: Pitting of flesh of Sturmer apples

and the flesh shows a dry, spongy condition near the stone. In plums and cherries also, brown pits appear in the flesh and there may be external malformation of fruits (Figs. 15, 17).

In raspberries boron deficiency causes die-back; some buds die during winter and others fail to make normal growth, producing "scorched" leaves. There is a premature growth of new canes.

Fruit Affected

This disorder has been recorded in apples, apricots, cherries, pears, plums, and raspberries in New Zealand. Although it affects both peaches and citrus in other countries, there are no reports of any effect on these crops in this country. The different reactions of apple varieties have been described above, but little is known of differential varietal effects on other fruits.

Economic Importance

Losses from boron deficiency are relatively easy to estimate because the fruit itself is affected. Boron deficiency of apples has undoubtedly been the most important single trace-element deficiency affecting fruit in this country. It has affected fruit in the Nelson district since 1912, and in the period 1923-35 caused serious losses. In one season fifty thousand cases of fruit were lost in this district. Since 1935, control methods have been available and losses have been negligible. Borax treatment is not so widely used in Central Otago and severe losses from internal cork have been reported within the past ten years.

Losses of pears, stone fruit, and raspberries have been on a smaller scale, but in some orchards have been serious.



FIG. 13

After Atkinson (1936)

Boron deficiency: Pitting of flesh of Jonathan apples

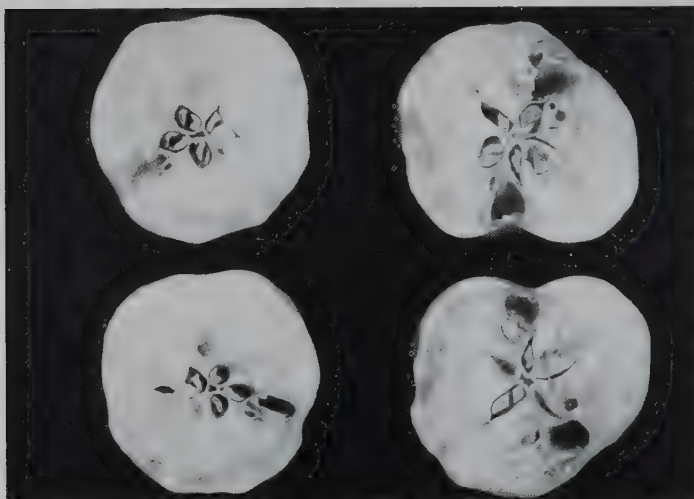


FIG. 14

After Atkinson (1936)

Boron deficiency: Pits and cavities in flesh of Washington apples



FIG. 15

Photo: L. H. Wright

Boron deficiency: External malformation of Greengage plums

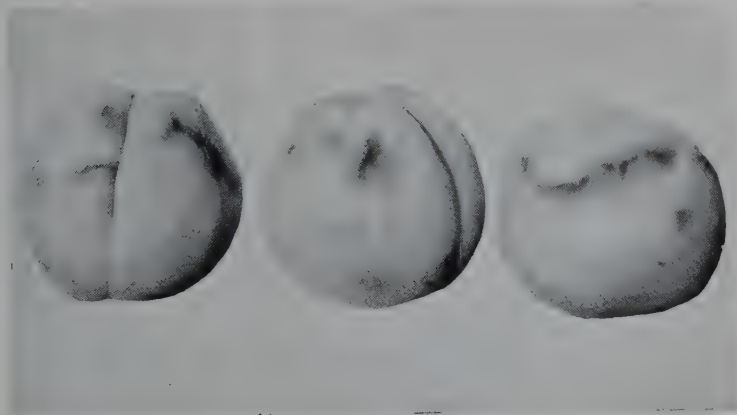


FIG. 16

Photo: R. Hughes

Boron deficiency: External malformation of Royal Apricots

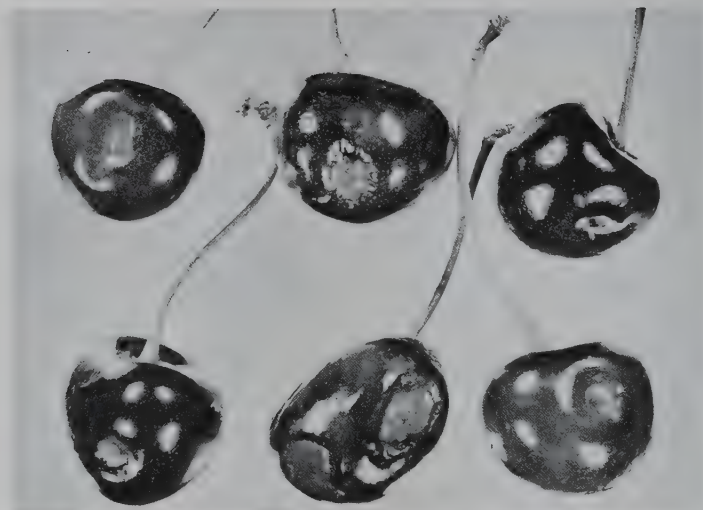


FIG. 17

Photo: L. H. Wright

Boron deficiency: External malformation of cherry fruits

Treatment

The disorder can be effectively controlled by soil dressings of borax at the rate of $\frac{1}{4}$ to $\frac{1}{2}$ lb. per tree. This is best, perhaps, applied in the spring. In cases of mild or moderate deficiency, dressings need only be made every other year. Where deficiency is acute, annual dressings may be necessary. Borax may be applied by itself spread over a circle of 6 ft. diameter with the trunk as centre, or an equivalent amount may be broadcast in the form of borated superphosphate.

It has been shown that dressings of over $\frac{1}{2}$ lb. borax per tree applied to the soil increase breakdown of Jonathan apples in storage. Attention has been drawn previously to the tree damage likely to be experienced if excessive soil dressings are used. There are dangers in applying too much borax.

Effective control can also be obtained by foliar sprays of borax at a strength of 1 to 2 lb. per 100 gal. No lime need be included in this spray. It is also possible to include borax, at the same strength, in one of the spring therapeutant sprays. Borax is compatible with lead arsenate, lime sulphur, and colloidal sulphur.

Careful consideration should be given before any lime applications are made in orchards in districts where boron is known to be deficient.

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Manganese Deficiency of Fruit Crops in New Zealand

Introduction

Early in this century French workers showed that manganese was essential for the growth of maize. Since that time evidence has steadily accumulated indicating that manganese is an essential element for all plant growth, and many pathological conditions shown by plants in the field have been proved to be caused by a deficiency of manganese.

These deficiency diseases are known in many parts of the world, and several crops are severely affected. Oats is a very susceptible crop, a deficiency producing a "grey speck" on the leaves. In peas a characteristic symptom "marsh spot" appears in the seeds. Manganese deficiency is also known to cause leaf chlorosis in a wide range of other plants.

Manganese deficiency occurs in a variety of soil types, but only rarely when the pH is below 6.5.

Incidence in New Zealand

In New Zealand, manganese deficiency has been observed occasionally on vegetable crops, e.g., tomatoes, potatoes, beans, beet, but it is in fruit crops that it has been observed to have its worst effects. Taylor and Burns (1938) recorded manganese deficiency on citrus in New Zealand. Atkinson (1944) and Bollard (1953) identified this deficiency on peaches

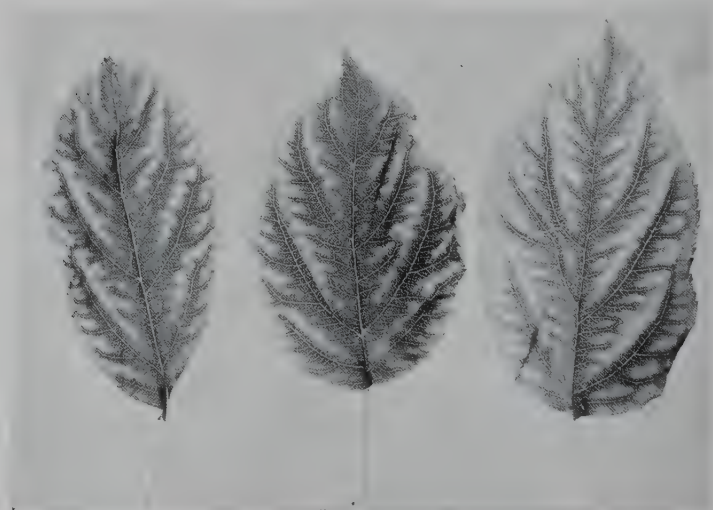


FIG. 18

Photo: S. A. Rumsey

Manganese deficiency: Chlorosis of apple leaves, var. Giant Geniton



FIG. 19

After Atkinson and Bollard (1953)

Manganese deficiency: Chlorosis of quince leaves; healthy leaf, top left. $\times 1$

and apricots respectively in Central Otago. The same deficiency in a range of fruits in Hawke's Bay was described by Atkinson and Bollard (1953). This deficiency has now been recorded in most districts from Kerikeri to Invercargill. It is particularly noticeable in Auckland, parts of Hawke's Bay, and Central Otago.



FIG. 20

Photo: J. W. Endt

Manganese deficiency: Chlorosis of plum leaves, var. Doris. $\times \frac{1}{3}$

Symptoms

The main symptom is leaf chlorosis, and the name "mottle leaf" has been applied to these disorders. The areas between the leaf veins become yellow and chlorosis appears to extend in from the edge of the leaf though, in some cases, only the leaf edge may be affected. A band of green tissue still remains along most of the veins, though in extreme cases the entire leaf may become chlorotic. Affected leaves are not confined to any one part of a shoot though the older leaves tend to show more severe chlorosis. Those leaves on an affected tree that do not show a chlorotic pattern may be a paler green than normal. Only a few leaves on a tree may show symptoms or nearly every leaf may be affected. In many cases the disorder does not show up till late in the season. The foregoing description applies to symptoms on all fruit crops affected though, of course, there are differences in detail between them (Figs. 18–26).

In addition to leaf chlorosis, severely affected trees show stunting, and with peaches, in one instance, deaths of trees occurred where manganese deficiency had been very severe owing to overliming.

Other deficiencies and other diseases cause leaf chloroses which often cannot be distinguished from manganese deficiency symptoms. Mild symptoms of magnesium deficiency in apples and of zinc in apricots and peaches are similar to the chloroses caused in these crops by manganese deficiency (Figs. 32, 33).



FIG. 21

Photo: S. A. Rumsey

Manganese deficiency: Chlorosis of peach leaves, var. Paragon. $\times 1$



FIG. 22

Photo: S. A. Rumsey

Manganese deficiency: Severe chlorosis of peach leaves, var. Paragon

Fruit Affected

Manganese deficiency has been observed in apples, apricots, citrus, cherries, passionfruit, peaches, plums, quinces, and raspberries in New Zealand. Apple, peach, and plum have been affected in Auckland, Hawke's Bay, and Central Otago. The only records in apricot and cherry



FIG. 23 *After Bollard (1953)*
Manganese deficiency: Chlorosis of apricot leaves, var. Roxburgh Red; healthy
leaf, top left. $\times \frac{1}{2}$



FIG. 24 *Photo: S. A. Rumsey*
Manganese deficiency: Chlorosis of raspberry leaves. $\times \frac{1}{2}$



FIG. 25

Photo: S. A. Rumsey

Manganese deficiency: Chlorosis of passionfruit leaves. $\times \frac{1}{3}$

come from Central Otago. The one instance of this deficiency in raspberries comes from Invercargill,* while the citrus and passionfruit records come from Auckland.

Most varieties of these fruits appear to be affected, but Paragon peaches and New Zealand grapefruit are particularly susceptible.

Economic Importance

Where death of trees has occurred, the importance of this deficiency is obvious but, in most cases, effects are less easy to assess in terms of decreased yield. In some cases the effects of deficiency have led to stunting, and it is probable that where leaf chlorosis is the only apparent symptom there is a reduction in growth or yield. For this reason every effort should be made to treat this deficiency wherever it shows even though it might be considered that there is no adverse effect on production. The fact that this deficiency affects fruit crops from Kerikeri to Invercargill perhaps indicates that its total effect would be large.

Treatment

The recommended method for treating this deficiency in all crops affected is a foliar spray of manganese sulphate, made up by mixing 3 lb. of manganese sulphate with 4 lb. of hydrated lime in 50 gal. water. Precautions observed in preparing Bordeaux mixture should also be observed here. A spray of manganese sulphate at the same strength but without lime can sometimes be safely and effectively applied, but on some crops

*Work carried out in collaboration with G. N. Paulin, Horticultural Inspector, Department of Agriculture.

severe leaf damage will result. For this reason it is recommended that lime be included at all times.

The time of application is important. Early spraying is desirable, yet there must be enough leaf area to absorb the required amount of solution. If spraying is delayed too long, the black spray deposit may still be apparent at harvest time. Thus application should be made as soon as three or four leaves are open on shoots, and no sprays should be applied later than the end of November. With early maturing peach and plum varieties spraying should be completed even earlier. Until more information is available sprays should be applied annually.

To avoid aggravating this deficiency, careful consideration should be given before any lime applications are made in orchards where symptoms of this deficiency have already appeared or where the pH is 6.0 or above.



FIG. 26

Photo: J. W. Endt

Manganese deficiency: Chlorosis of New Zealand grapefruit leaves; healthy leaf on left. $\times \frac{1}{2}$

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Zinc Deficiency of Fruit Crops in New Zealand

Introduction

The same French workers who showed that manganese was an essential element for plant growth also suggested that zinc came into the same category. Subsequent evidence has substantiated this, though the range of plant species known to be affected in the field by zinc deficiency is not as great as with manganese deficiency.

Zinc deficiency is now known to occur in many countries, and is recognized as the cause of serious disorders in pecan, tung, maize, and *Pinus*. The serious disorders caused in citrus and deciduous fruit trees are also widespread. This deficiency commonly occurs on the lighter soils, particularly on sandy areas, and it is aggravated by high soil pH.

Incidence in New Zealand

In New Zealand, this deficiency has been observed on fruit crops only. Forester (1947) and Reynolds (1947) both claimed to have demonstrated zinc deficiency in apples on their own orchards in Auckland and Nelson respectively. Bollard (1953a, b) described this deficiency on pears, peaches, and nectarines in the Alexandra district of Central Otago. It is now (1954) known in apricots,* and has been observed in many parts of the Central Otago fruitgrowing area. Recent work has shown that this deficiency affects sweet orange trees in the Kerikeri district. This work is incomplete and the extent of this deficiency in this district is not yet clear, but it is definitely serious in some orchards.

Despite the two reports quoted, zinc deficiency has not since been observed in either Auckland or Nelson, and it would seem that it does not occur extensively in either of these districts. Watson (1950) made a survey of the zinc content of leaves and spurs from apple trees of four varieties throughout the Nelson district. In no case were levels of zinc unduly low.

Symptoms

One of the first symptoms is a leaf chlorosis and, in mild cases, this may be the only symptom (Figs. 28, 34, 35). With some fruits, e.g., peaches and apricots, this leaf chlorosis is difficult or impossible to distinguish from similar symptoms caused by manganese deficiency (Figs. 32, 33).

*Work carried out in 1953-54 in collaboration with W. S. Kemp, Horticultural Instructor, Department of Agriculture.



FIG. 27

After Bollard (1953a)

Zinc deficiency: Lack of terminal growth and "little leaf" of pear, var. Williams Bon Chretien

However, in most cases of zinc deficiency more extensive symptoms also appear. Leaves are smaller, perhaps only a quarter or less of normal size, and they may occur in rosettes because shoots do not make their normal growth. These two types of symptoms give rise to the popular names "little leaf" and "rosette" frequently applied to zinc-deficiency



FIG. 28

After Bollard (1953b)

Zinc deficiency: Chlorosis of peach leaves, var. Royal George: healthy leaf on left. $\times \frac{1}{2}$



FIG. 29

After Bollard (1953b)

Zinc deficiency: Leaders of peach tree, var. Muir. One leader showing die-back, another showing "little leaf" and rosetting, and a third showing leaf chlorosis only



FIG. 30

Photo: J. W. Endt

Zinc deficiency: Leaf chlorosis and "little leaf" of apricot shoot, var. Newcastle

disorders (Figs. 30, 31). Rosetting of shoots may also occur. Restriction of growth is often seen, particularly in the upper parts of trees. In many cases buds fail to grow and leaders may show no apparent growth for 2 to 3 ft. from the tip. In the most severely affected trees the leaders die back (Figs. 27, 29).

Within a tree, symptom development is sometimes irregular, one leader may be showing severe die-back while others show only slight symptoms. There is a suggestion that in peaches and nectarines zinc deficiency can cause fruit drop without causing other symptoms.



FIG. 31 Photo: J. W. Endt
Zinc deficiency: Moorpark apricot, healthy shoot on left, shoot showing rosetting, "little leaf", and leaf chlorosis on right. $\times \frac{1}{6}$

Fruit Affected

The two isolated cases from Auckland and Nelson are the only reports of this disorder in apples in New Zealand. Symptoms similar to those caused by zinc deficiency have been seen in apples in the Ettrick district, but these have not responded to zinc treatment.

This disorder has been observed in pears, plums, peaches, nectarines, and apricots in Central Otago. Little is yet known about the differential reaction of our varieties, but among apricots the variety Newcastle seems to be one of the more susceptible. In Kerikeri two varieties of sweet orange (Carter's Navel and Mediterranean Sweet) have responded to zinc treatment. It is likely that other citrus varieties may also be affected in this district.



FIG. 32

After Bollard (1953b)

Similarity of leaf chloroses in peach: Manganese deficiency on left; zinc deficiency on right. $\times 1$

Economic Importance

In New Zealand, this deficiency is of commercial importance in Central Otago and Kerikeri. In some orchards it has affected whole blocks of trees, reducing their cropping capacity by over 50 per cent. Elsewhere the effects are harder to assess because of the difficulty of measuring reduction of growth and yield. In one orchard where young apricot trees



FIG. 33

Photo: S. A. Rumsey

Similarity of leaf chloroses in apricot: Manganese deficiency on left; zinc deficiency on right. $\times \frac{2}{3}$



FIG. 34

Photo: J. W. Endt

Zinc deficiency: Leaf chlorosis of Mediterranean sweet orange. $\times \frac{3}{4}$

were affected, the effects of zinc treatment were spectacular. As with manganese deficiency, it is urged that every effort be made to treat the deficiency once it shows up and also to treat the entire block and not just the obviously affected trees.

Treatment

Work in New Zealand has not been extensive enough to compare different spray programmes for treating this disorder. In all cases encountered a spray made up of 3 lb. of zinc sulphate with 4 lb. of hydrated lime in 50 gal. water was used and this has proved effective. Precautions observed in preparing Bordeaux mixture should also be observed here. Spraying should be carried out on deciduous trees as soon as three or four leaves are open on the shoots. The residues from zinc sprays are not a cause of concern but, in order to obtain maximum benefit, sprays should be applied before the end of November. Until more information is available sprays should be applied annually.

Overseas work in general favours dormant spraying of deciduous trees. In badly affected orchards, sprays of 5 per cent (50 lb. in 100 gal.) zinc sulphate are used or, in less severe cases, 2.5 per cent. For trees only slightly affected or for trees that have received strong sprays for two or three years a 1 per cent spray annually or a 2.5 per cent spray every other year is used. Dormant sprays can be safely applied without hydrated lime, but weeds and cover crops below treated trees will probably be killed.

As with manganese deficiency, any projected lime applications in deficient areas should be carefully considered.



FIG. 35

Photo: J. W. Endt

Zinc deficiency: Leaf chlorosis of sweet orange, var. Carter's Navel. $\times \frac{1}{2}$

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